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Research paper

Mixed hydrothermal and meteoric fluids evidenced by unusual H- and O-isotope compositions of kaolinite-halloysite in the Fe(-Mn) Tamra deposit (Nefza district, NW Tunisia)

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ABSTRACT

The iron mine of Tamra (Nefza District, NW Tunisia) is a 50 m thick Upper Mio-Pliocene sedimentary series impregnated by Fe-Mn oxides associated with white clay lenses with high halloysite and kaolinite content. This mineralization results from i) synsedimentary weathering/pedogenesis, and ii) mixing surface water and regional hydrothermal fluids. The oxygen and hydrogen isotope composition of halloysite-kaolinite and goethite-hematite is examined in order to provide new insights into the ore formation. This study concludes that halloysite-kaolinite was not equilibrated only with meteoric fluids: the δ^{18}O values have a range towards high values that are not consistent with weathering conditions for their formation and/or during their subsequent alteration. The δD and δ^{18}O values of goethite lead to the same conclusion. The stable isotope compositions could be related to fluid-rock interaction with the underlying marls (and/or skarns), providing relatively high δ^{18}O values to the fluids responsible for the white clay formation. This model also shows that the Pb-isotope compositions of halloysite-kaolinite are explained by a felsic and a carbonated end-member, similar to other ore deposits (IOCG and Sedex) of the vicinity. Several factors should be considered for the precipitation of halloysite-kaolinite and/or destabilization of primary clays in the Tamra ore, i.e. mixing of deep hot saline fluids, related to a thermally driven circulation, and meteoric waters. This hydrothermal contribution postdates the main synsedimentary weathering/pedogenetic Fe-enrichment and may be related to late Fe, Mn, Pb, Zn and As inputs of the Fe-Mn oxides.

1. Introduction

In the weathering environment, the isotopic composition of hydrogen and oxygen in water is related to the climatic conditions (Savin and Epstein, 1970). Some authigenic clay minerals and goethite are known to crystallize in isotopic equilibrium with meteoric water and, once crystallized, are resistant to isotopic exchange under the near surface conditions thanks to the slow isotopic exchange at low temperature (Yapp, 1990; Sheppard and Gilg, 1996; Savin and Hsieh, 1998). Sheppard and Gilg (1996) showed that oxygen and hydrogen composition of present-day kaolinite formed from meteoric water is largely temperature dependent and aligned along the “kaolinite line”, which is parallel to the meteoric water line. Yapp (1990) drew the same conclusion for supergene goethite. Therefore, any process (diagenesis, evaporation, hydrothermalism…) which do not equilibrate goethite and kaolinite with meteoric waters would record a shift in the oxygen and hydrogen isotope composition. In natural systems, processes of fluid/rock interactions could lead to isotopic exchange between a mineralizing fluid and bedrocks for example, but also between a matrix progressively infiltrated by external fluids in an open system (Savin and Lee, 1988). Dissolution-precipitation of minerals could change the isotopic composition of the fluid (weathering, hydrothermal, diagenetic). This is especially the case for oxygen, given its availability in most of the common minerals (i.e. silicates, oxides, and carbonates)

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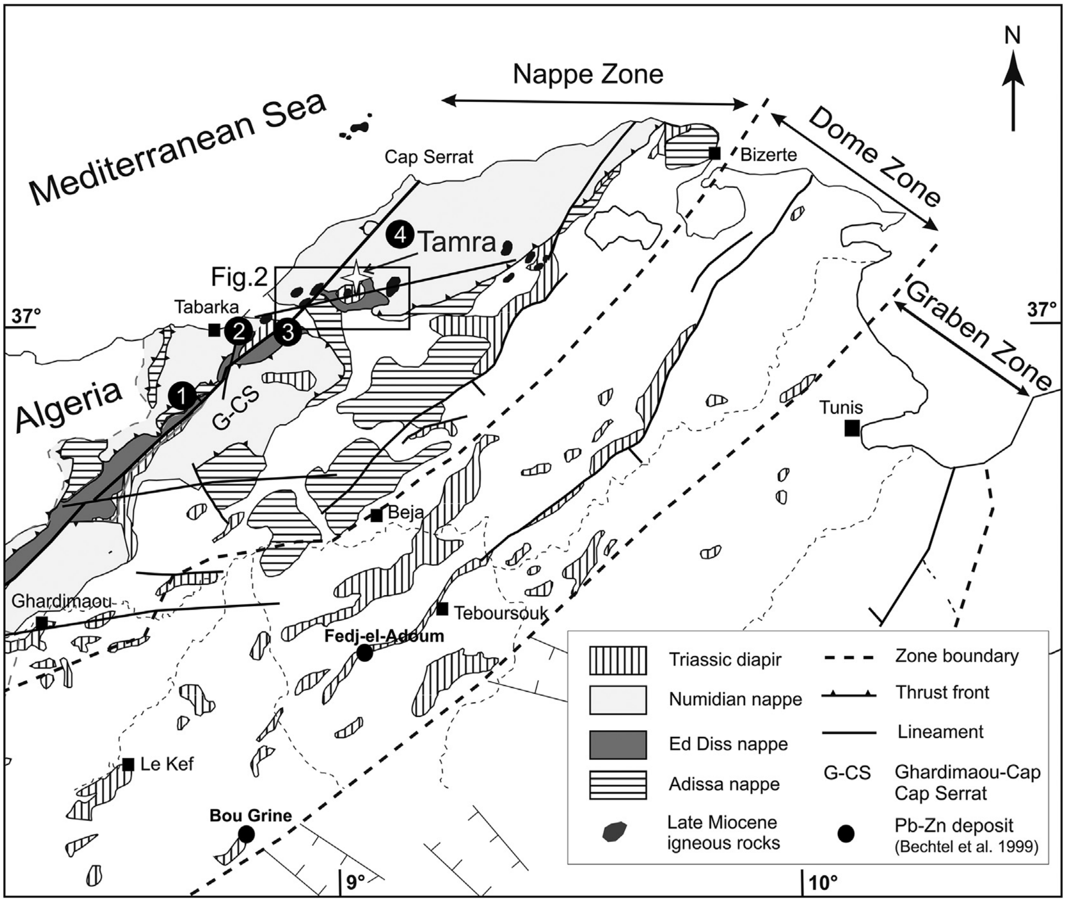

Fig. 1. Tectonic map of central and northern Tunisia showing the location of the Nefza area (Fig. 2) and the Bou Grine and Fedj-el-Adoun Pb-Zn deposits. Numbers refer to sampling site: 1-Ain Drahan (14AD01), 2-Sidi Bader (14SB01, 14SB02), 3-Ain Sebaa (14ME02), 4-Om-Tébal (OMS2; modified after Rouvier et al., 1985; Bouaziz et al., 2002; Bouhlel et al., 2013; Decrée et al., 2016).

compared to hydrogen (hydroxides, hydrous silicates). For example, carbonates concentrate ^{18}O in their structure in contrast to other minerals (Garlick, 1966; Taylor, 1968; Kohn and Valley, 1998a, b, c; Hoefs, 2009), and when dissolved, release heavy oxygen to the fluids, which are depleted in ^{18}O (meteoric fluids). However, the range of these modifications depends on the isotopic fractionation, on the initial difference in isotopic composition between the fluid and the mineral, and on the temperature between the mineralizing fluid and minerals (Girard and Fouillac, 1995).

The Nefza mining district (NW Tunisia) illustrates well the complexity of mixing fluids and their interaction with volcanic and sedimentary rocks during the genesis of various types of deposits (Figs. 1 and 2; Decrée et al., 2008a, 2013, 2014, 2016; Moussi et al., 2011). The area has successively been affected by Serravalian to Tortonian felsic magmatism, which is responsible for contact metamorphism of Late Cretaceous to Eocene marls into skarn (Decrée et al., 2014), and also for the setting up of a Miocene Fe-Cu-Au-(U-REE) volcanic breccia around a Triassic diapiric dome (Decrée et al., 2013). The extensional conditions allowed the generation of Tortonian to Messinian basaltic flows and the deposition of two Late Miocene to Pliocene continental (siliciclastic and carbonate) deposits containing the Sidi Driss SEDEX Pb-Zn (Sidi Driss) and the Tamra Fe(-Mn) deposits (Decrée et al., 2008a, b, 2010). The synsedimentary weathering/pedogenesis through the 50 m thick Tamra sediments and the later hydrothermal circulation have led to enrichment in Fe and other elements in the sediments (Decrée et al., 2008b, 2010). Local concentration of “white clays” composed of kaolinite and halloysite is associated with the Fe-oxide ore (Moussi et al., 2011), and is considered to determine both meteoric and hydrothermal contributions. Therefore, hydrogen and oxygen isotope analyzes of the white clays, associated with iron oxides and hydroxides, may help to redefine the process, which took place during mineralization in the Nefza mining district, taking into account the complexity and relationships of the rock varieties.

2. Geological settings

2.1. Geological framework

The Tamra Fe-Mn deposit is located in the Nefza mining district (NW of Tunisia, Fig. 1), which has been well-known for its base-metal deposits since the first half of the 20th century (Gottis and Sainfeld, 1952). The Nefza district is located in the Tellian “Nappe Zone” of Northern Tunisia, which is characterized by the Ed Diss Upper Cretaceous to Eocene thrust sheets (Burollet, 1991; Rouvier, 1994; Ould Bagga et al., 2006), and the overlying Oligocene “Numidian Nappe” (Fig. 1, Rouvier, 1977). Carbonates and marls from the Ed Diss sheet (Negra, 1987) are overlain by the “Numidian Nappe”, which is composed of claystones and sandstones Oligocene to Burdigalian in age. Serravalian to Late Tortonian felsic magmatism (12.9 ± 0.5 Ma to 8.2 ± 0.4 Ma; Badgasarian, 1972; Bellon, 1976; Rouvier, 1977; Faul and Foland, 1980; Decrée et al., 2013) resulted in the emplacement of granodiorite and volcanic rhyodacite (Mauduit, 1978; Rouvier, 1994; Savelli, 2002; Decrée et al., 2014). Skarn deposits were formed in contact with late Cretaceous-Eocene marls (Fig. 2; Decrée et al., 2013). The most prominent feature of the area is the 7 km long and 3 km wide Oued Belif ring-shaped structure (Rouvier, 1987), characterized by a Fe-rich breccia containing reworked fragments of the regional substrates, and a small amount of volcanic-related material (Decrée et al.,